CRT : Calibration issues

November 2009 test campaign data analysis

CRT review @ Fermilab
May 2010

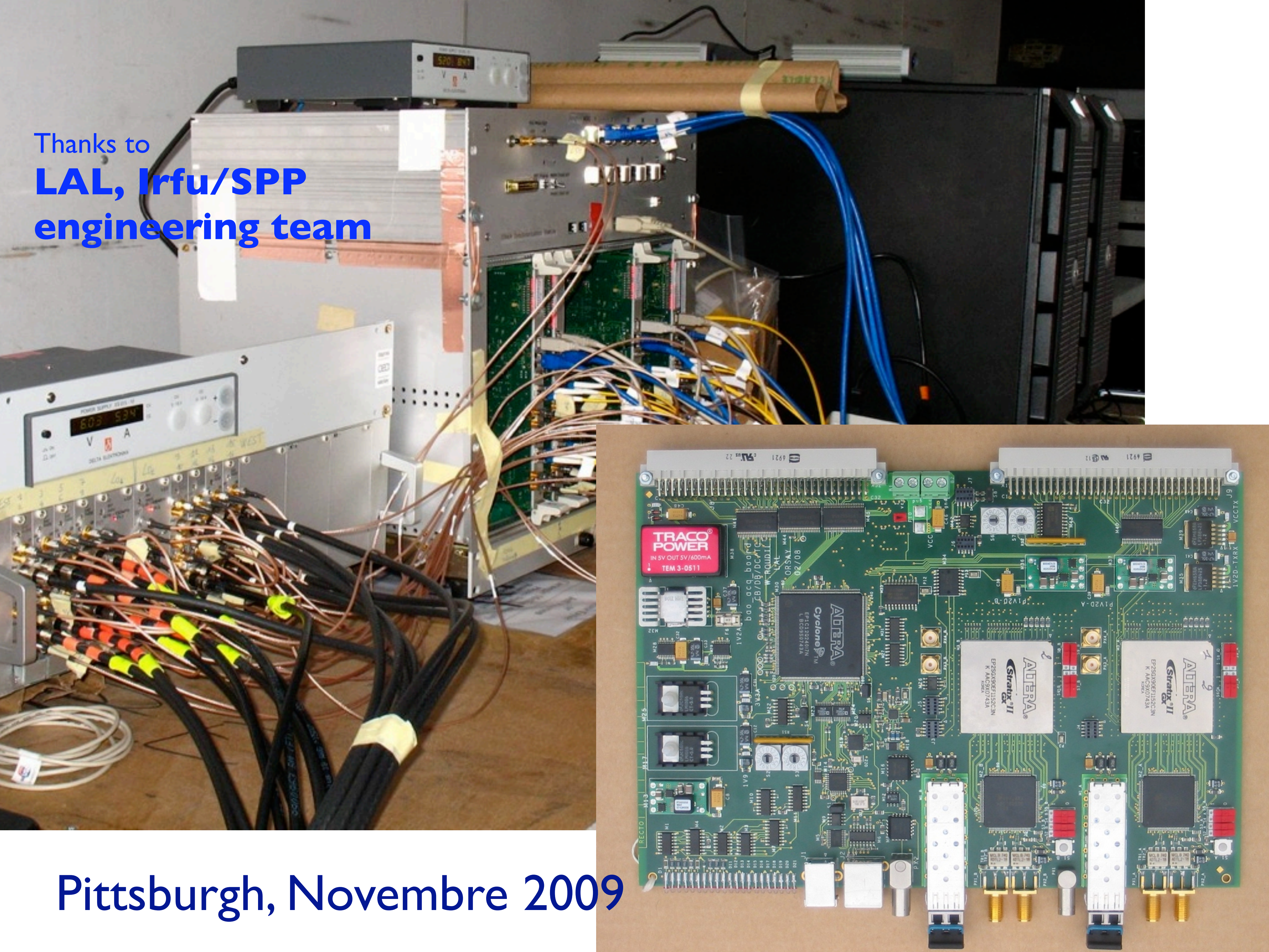
Christophe Magneville
IRFU / SPP

- Electronic chain and beam forming test campaign at Pittsburgh, **November 2009**
- Eight (8) dipoles (+LNA / RF filter) used on each CMU cylindrical reflector : total 16 channels
- Saclay-Orsay Electronic chain
  - Analog module: Amplifier/Mixer/Filter
  - 16 x 500 MHz digitizer channels (4 boards x 4 ch) with FFT on FPGA
  - 8 x 5 Gbit/s optical fiber data transmission to acquisition computer
  - Object oriented (C++) acquisition and processing software

Thanks to

J. Peterson
K. Bandura
B. Taylor

CMU cylinders at Pittsburgh



Thanks to

LAL, Irfu/SPP engineering team

Pittsburgh, Novembre 2009

West 1 2 3 4 5 6 7 8

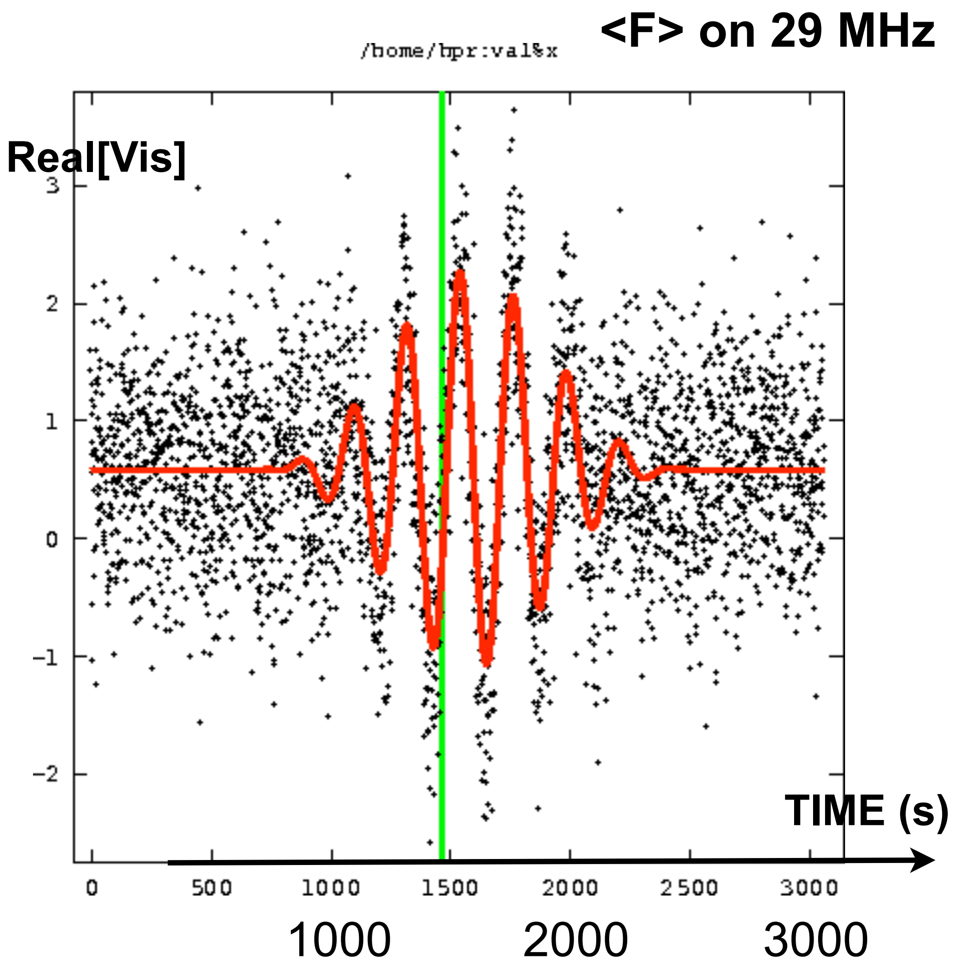
South **North**

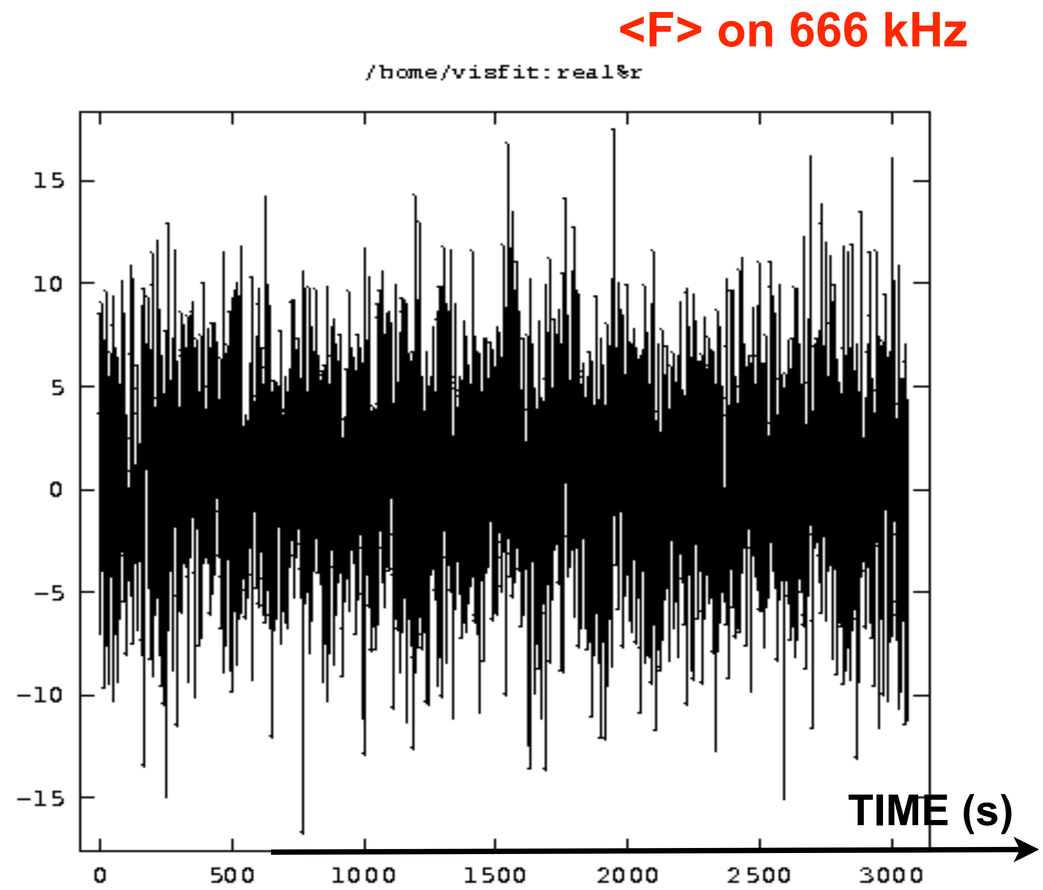
East 1 2 3 4 5 6 7 8

- Compute East dipole- West dipole visibilities <Ei Wj*> (8^2=64 visibilities)
- Time average ~ 1 sec , frequency average ~ 666 kHz , Total Bandwidth ~ 29.3 MHz (FFT resolution = ~ 61 kHz)
- Observed sources : CygA (89 deg), CasA (71 deg), Sun (29 deg) on November 23rd, 24th
- Low duty cycle acquisition (2-3%) in Nov. 2009 due to acquisition computer limitations. Current digitizer board can handle 50% duty cycle

- Fit fringes model on each of the 64 <Ei Wj*>(time)

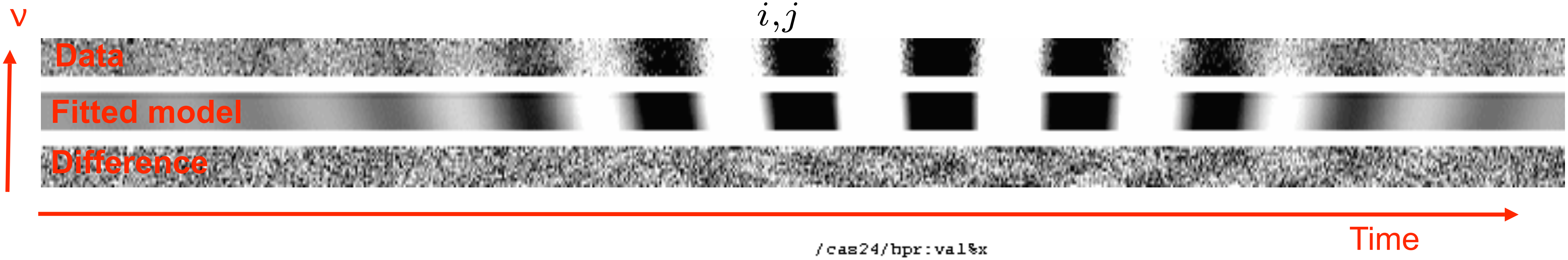
- Gives relative complex gain - amplitude/phase ($g_i\ g_j^*$) (for each visibility (dipole pair)



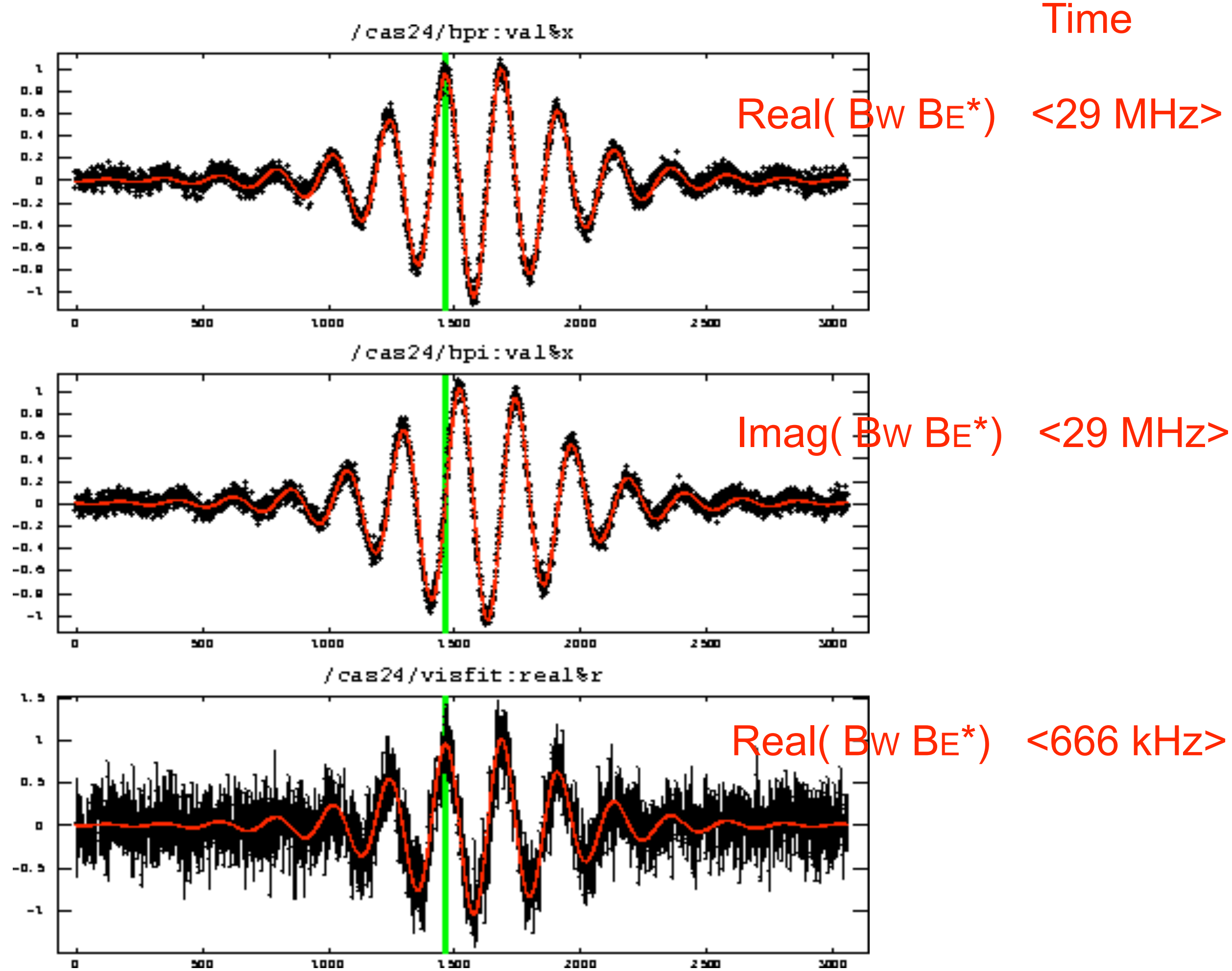


North-South digital beam formed toward CasA

$$< B_W B_E^* >= \sum_{i,j} < E_i W_j^* >_{corr}$$

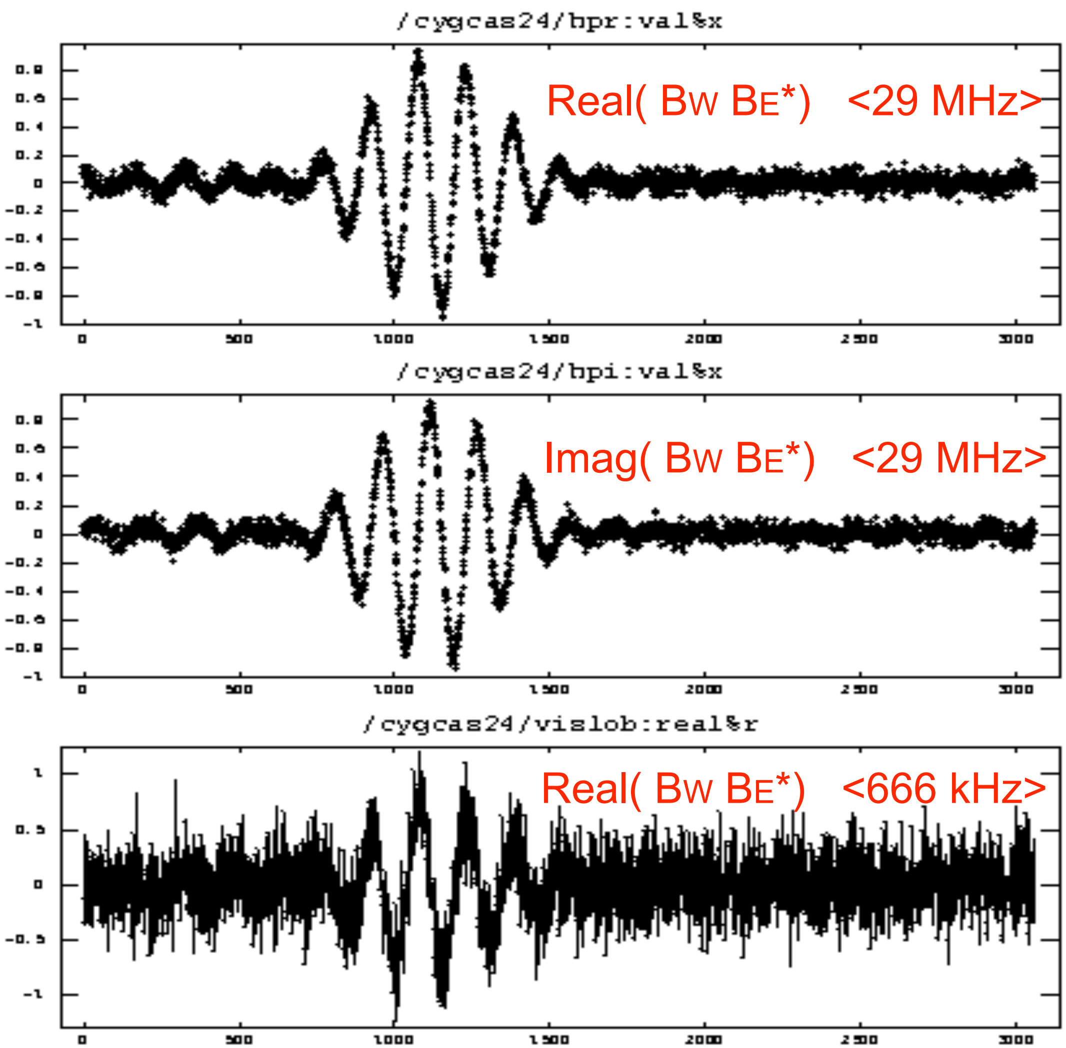


- Correct each dipole-dipole visibility for the complex gain
- Combine them to form a digital beam



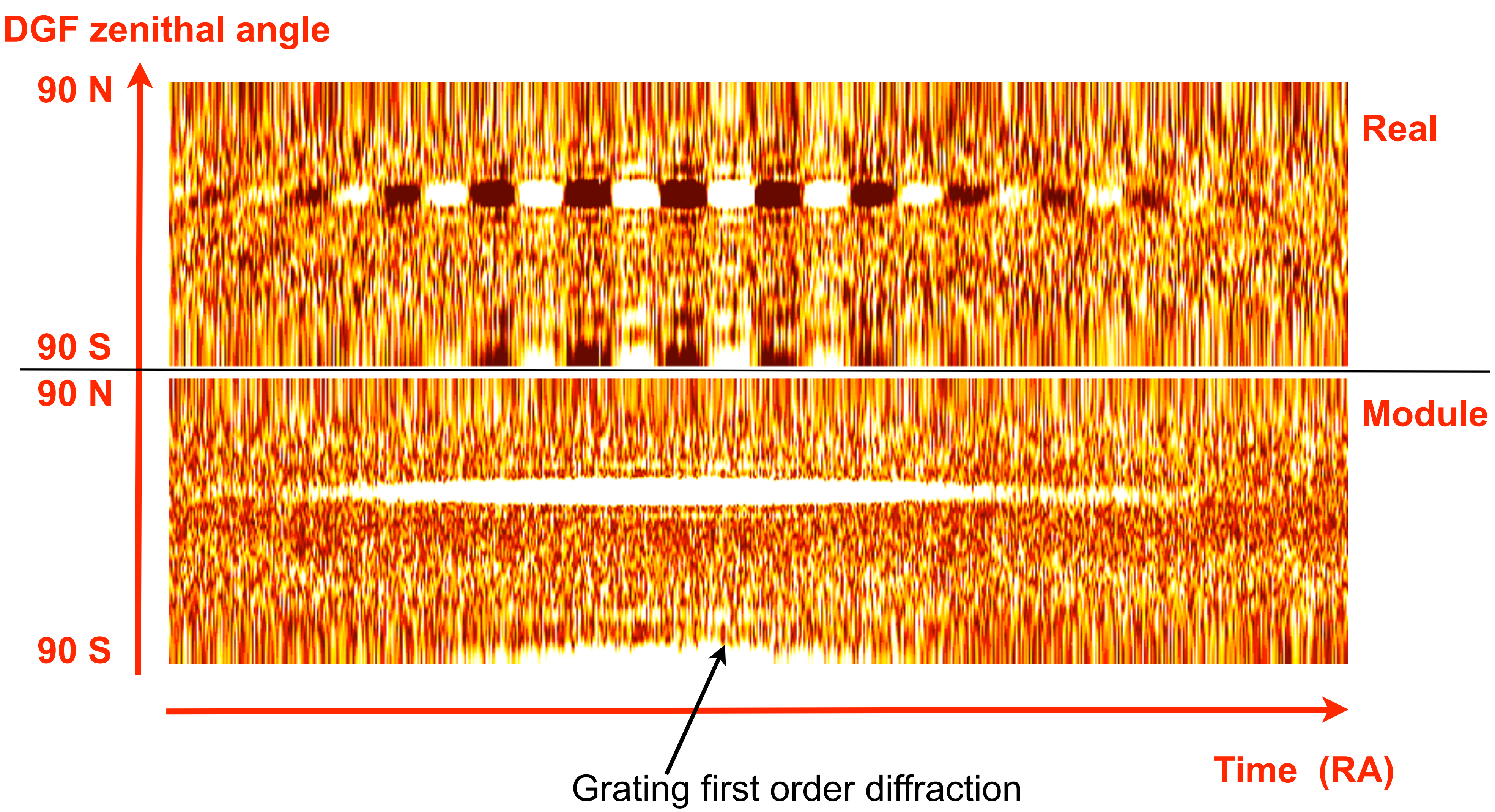
North-South digital beam formed toward CygA

$$< B_W B_E^* >= \sum_{i,j} < E_i W_j^* >_{corr} \times \exp\left[-2i\pi \frac{\Delta x_{ij}}{\lambda}(\sin z_{CygA} - \sin z_{CasA})\right]$$

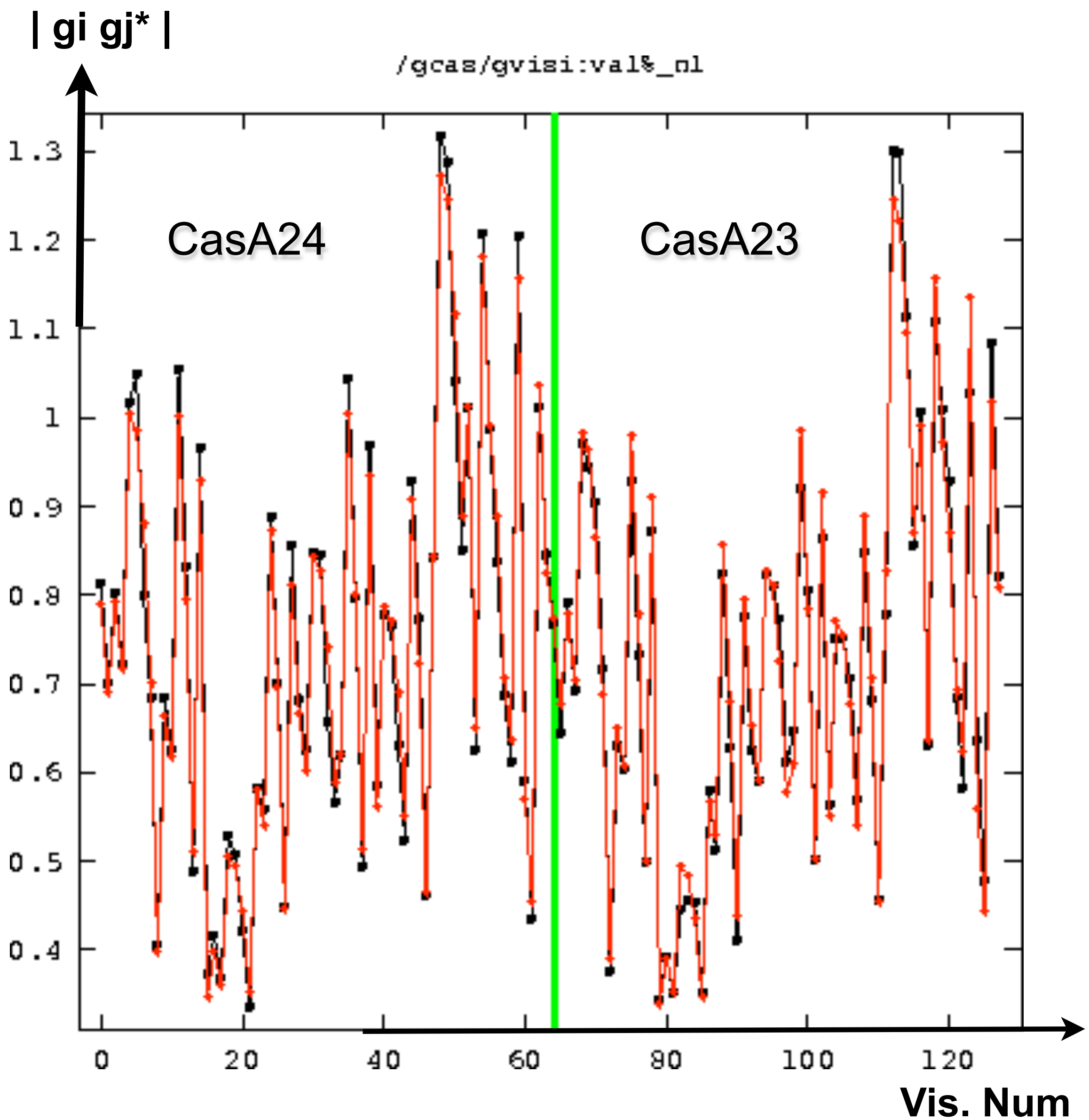


Correct each dipole-dipole visibility for the complex gains **computed on CasA**

2D digital beam forming on CasA (<29 MHz>)



Individual antenna gain - module

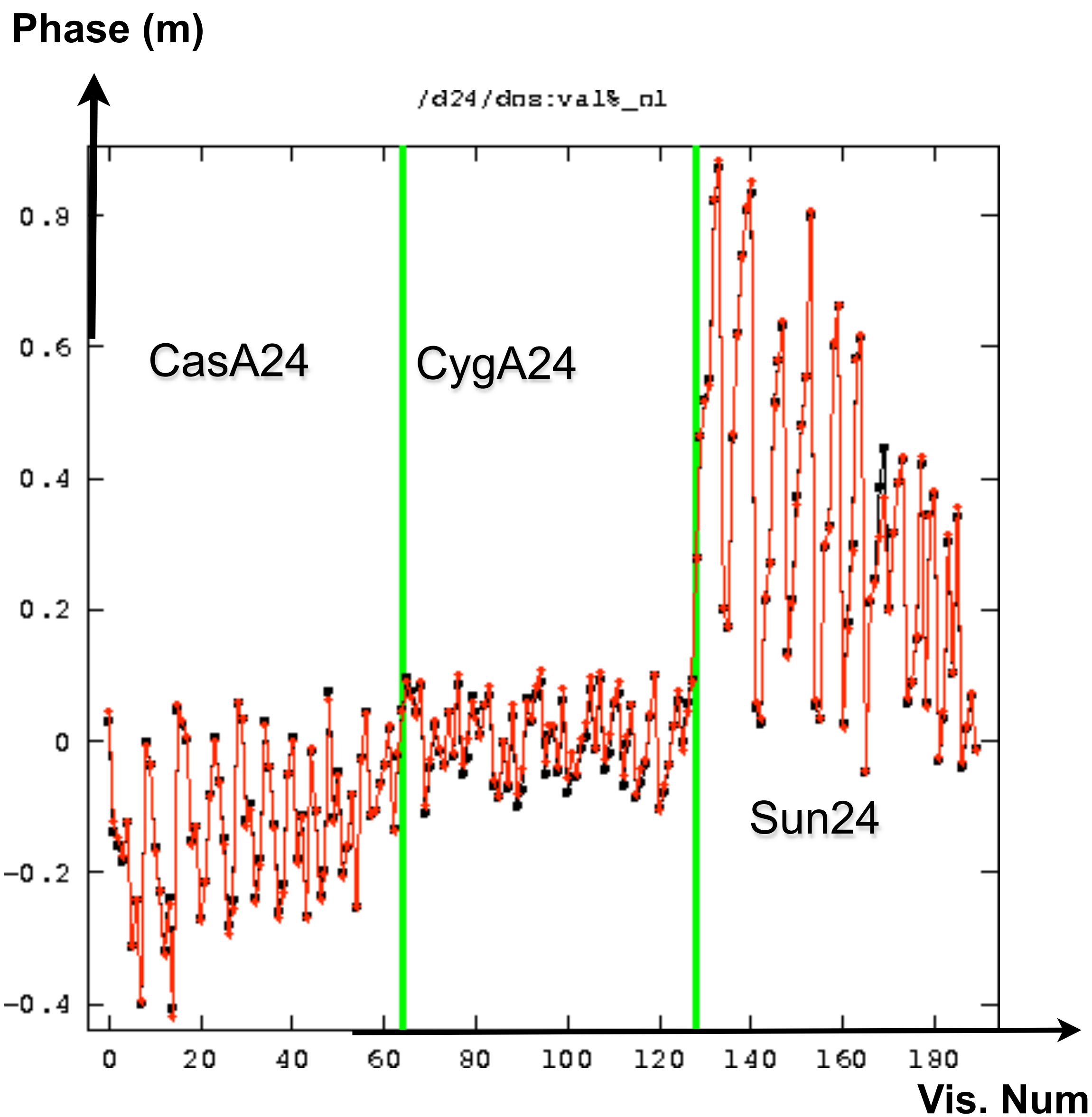


Black = visibility gain datas

Red = fitted gain model , from individual dipole gains

- FFT beam forming requires the knowledge of individual dipole gains
- Determine the 16 dipole complex gains (g_i) using redundancies (64 $g_i\, g_j^*$ visibility gains)
- Gains dispersion about 6dB (factor ~4) for around 90dB gain
- RMS model/gains ~ 1%

Individual antenna gain - phase



- RMS model/phase ~ cm

Black = visibility phase datas

Red = fitted phase model from individual dipole gains

Future calibration plan

- Reasonable determination of dipole complex gains despite the low signal / noise ratio in november (due to acquisition limitations)
- Significant increase in duty cycle (x 5) foreseen for the next observation campaign in fall 2010. 100% duty cycle (efficiency) envisaged for future
- Better S/N ratio → increase in number of calibration sources
- Complementary calibration methods (Work in progress by **J. Marriner / FNAL**)

- The calibration strategy will include at least two time scales:
  - short time scale (10'-1 hour) monitoring, possibly using artificial excitation systems (capacitive coupling or far field source)
  - long time scale (~ day) and antenna pattern monitoring using multiple sources on sky
  - Large number of calibration sources will allow us to monitor the complex gains and determine angular and frequency response for each receiver (dipole)
- The computation of visibilities will be multiplex in time (not all visibilities are computed at once)
- Future observations at Pittsburgh (and Nancay) will allow us to refine the calibration scheme (fall 2010)

Backup

Fitted Model for E-W visibilities

- <S1.S2*> = ($M_{re}(F)$ + j $M_{im}(F)$)

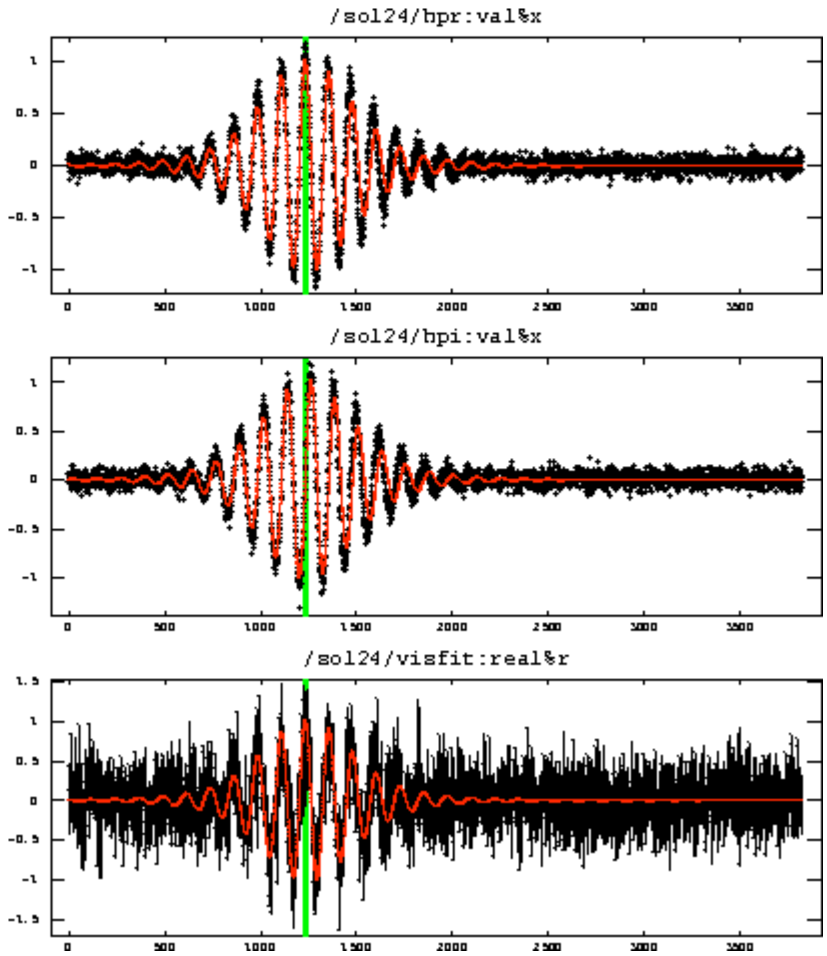
  + G * R(F) * Lobe(W_{cyl},q_0) * exp{ 2 j p F/c * [d + d'*(F-F_0)/F_0

  - (25m+D) * 1.003 * cos(d) *(t-t_{max})] }

  - Clean data for RFI !!!!!
  - $M_{re}(F)$, $M_{im}(F)$: fit for flat correlated noise
  - G * R(F) = one G , FIX freq shape with media filtering on data
  - t = time, t_{max} = time of transit <u>FIXED</u>
  - F = frequency , F_0 = central frequency
  - Lobe = lobe E-W = sin(X)/X <u>LIMIT AT FIRST ZERO</u>
    - X = p W_{cyl} / l * (-1.003 * cos(d) *(t-t_{max}) + q_0)
  - d = path N-S + electronic delay , d' = freq depend delay
  - D = extra path delay E-W (w.r.t. 25m) <u>FIXED</u>
- Fit 1D in (t) by averaging in <F> OR Fit 2D in (t,F)

- Time average ~ 1 sec , frequency average ~ 666 kHz , BW ~ 29.3 MHz

Sun24nov lobe self-calib



Lower delta -> more fringes

Also larger cyl width -> more fringes

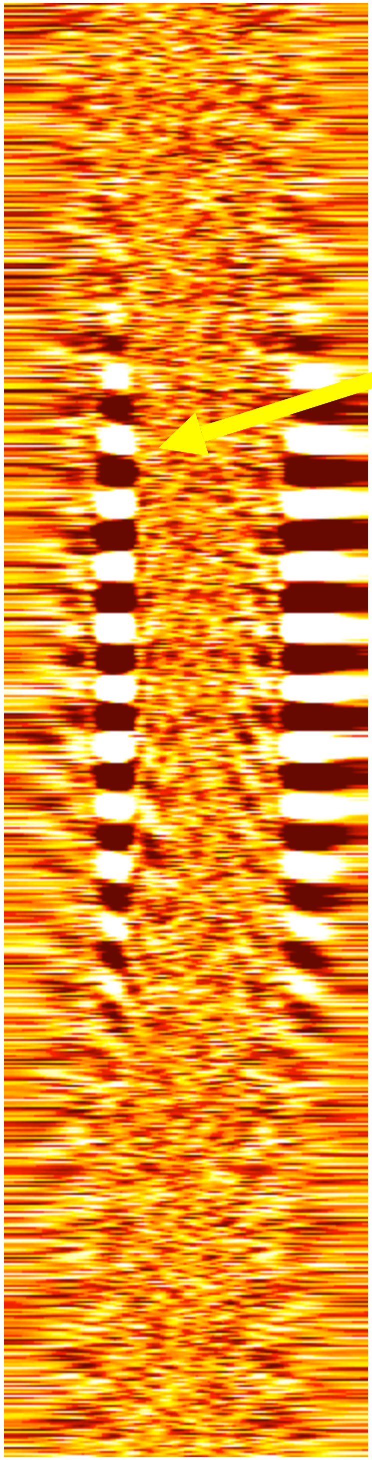
Low elevation -> model not so good

See residual on 2D plot

Cylinder width on lobe*lobe

- Redo fit on <lobe * lobe> and compute:
  - CasA24: Wcyl = 6.77 m
  - CasA23: Wcyl = 6.69 m
  - CygA24: Wcyl = 7.56 m
  - CygA23: Wcyl = 7.47 m
  - Sun24: Wcyl = 4.90 m
  - Sun23: Wcyl = 5.00 m

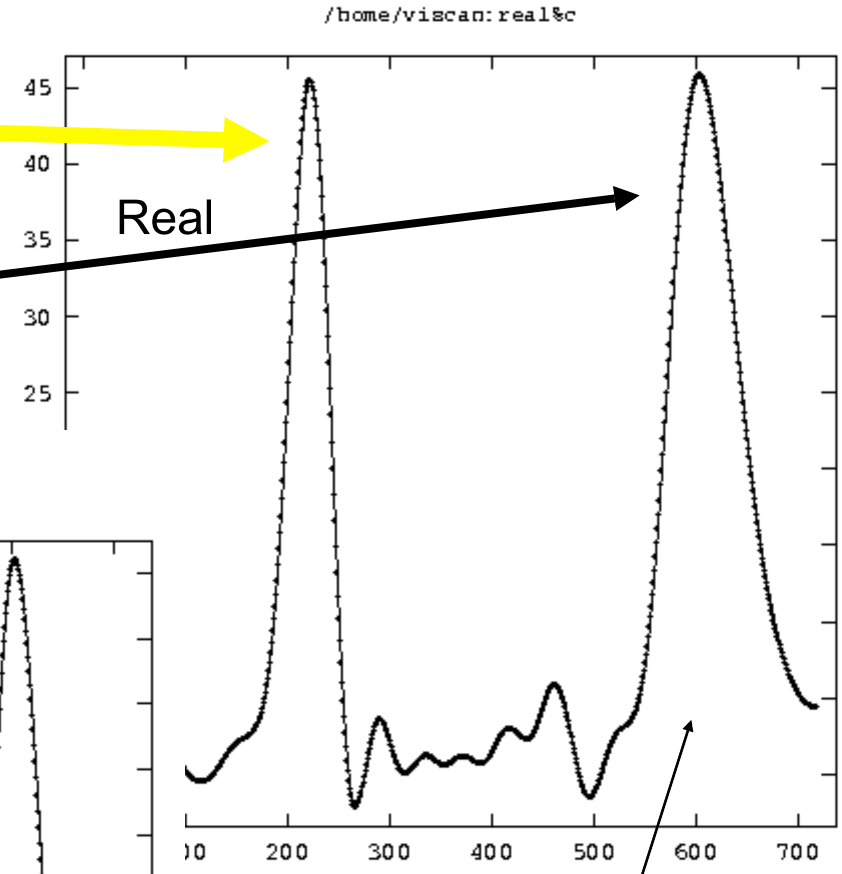
Scan lobe N-S for SunA24nov <29 MHz>



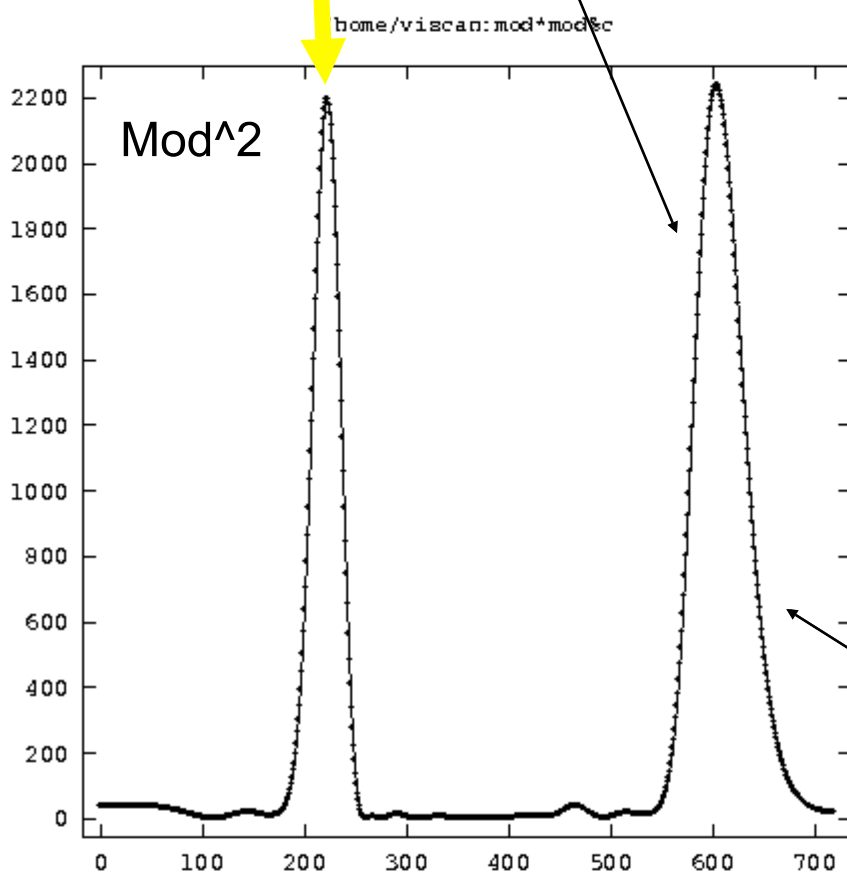
Real

Nyquist

Sun



90N zenith 90S

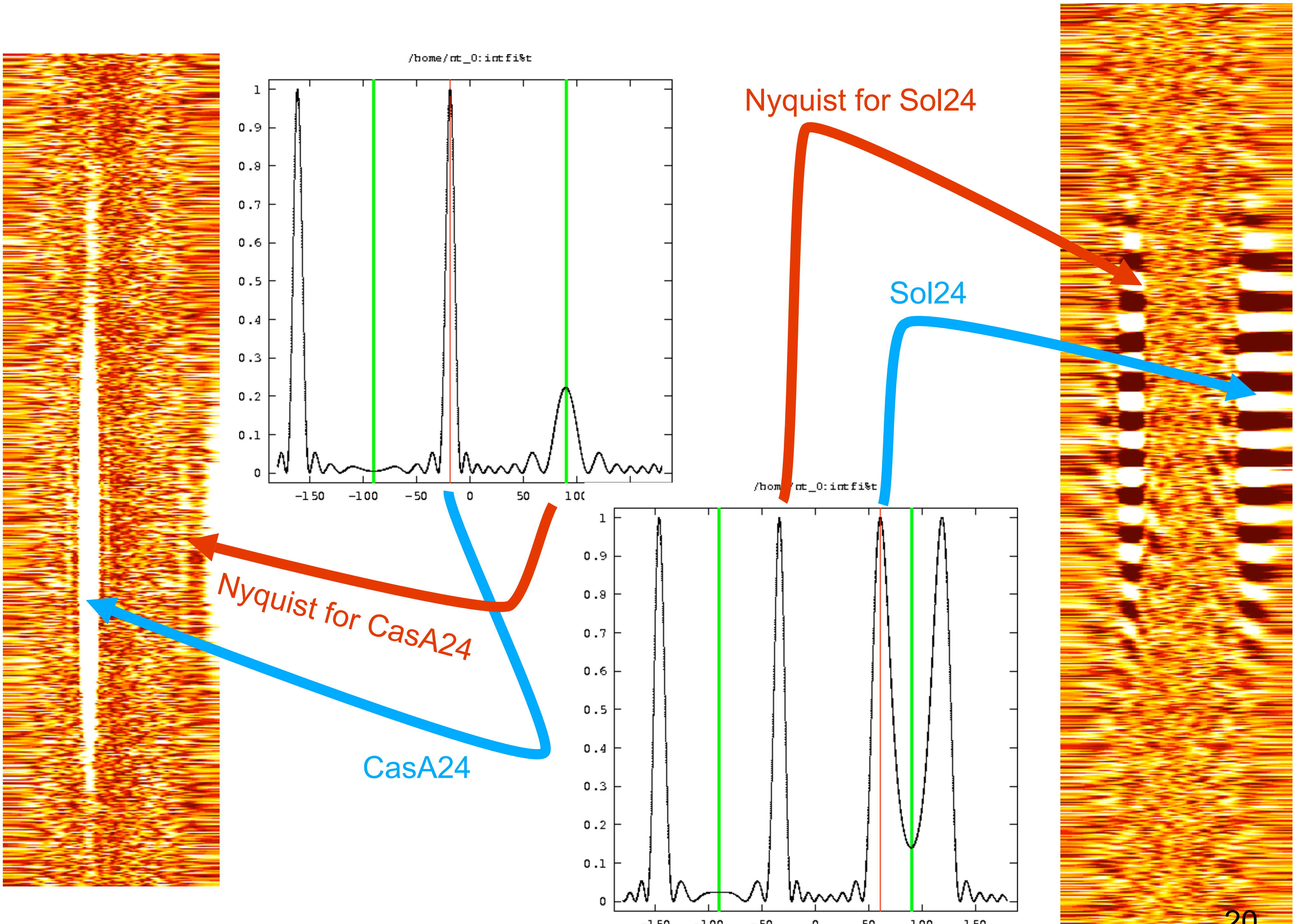


Non-sym. Shape

Remember that N-S lobe is

sin(N*x)/sin(x) with x=sin(q)

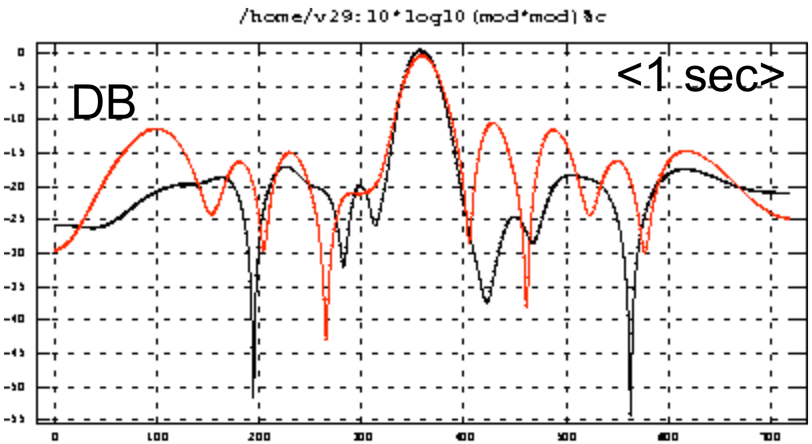
Grating lobes computation for SunA24 and CasA24

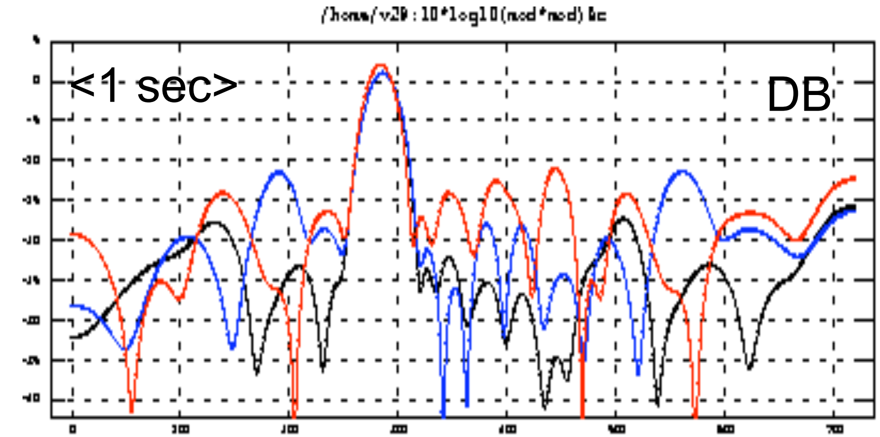


N-S lobe shape

CygA24 ~ Zenith

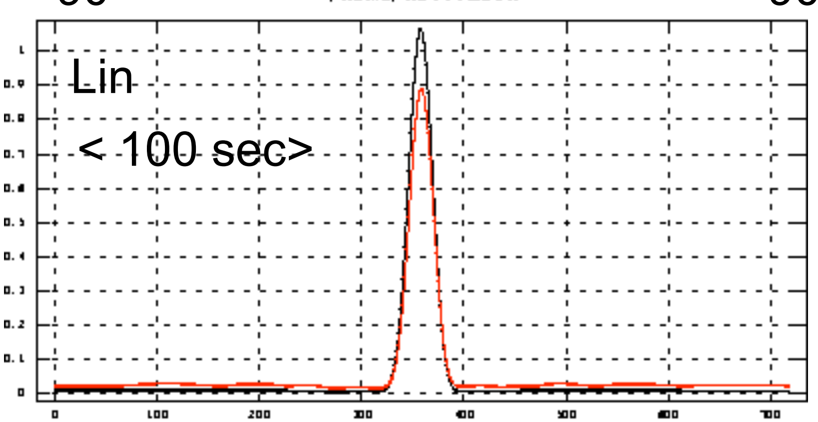
CasA24 ~ 20 deg from zenith



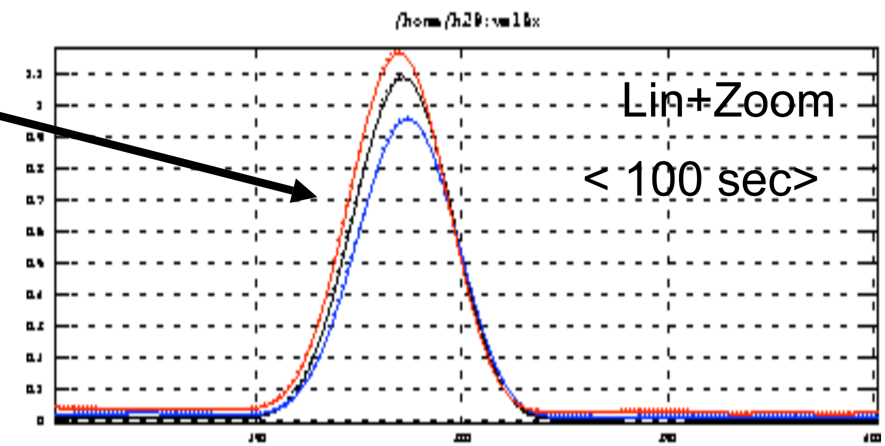


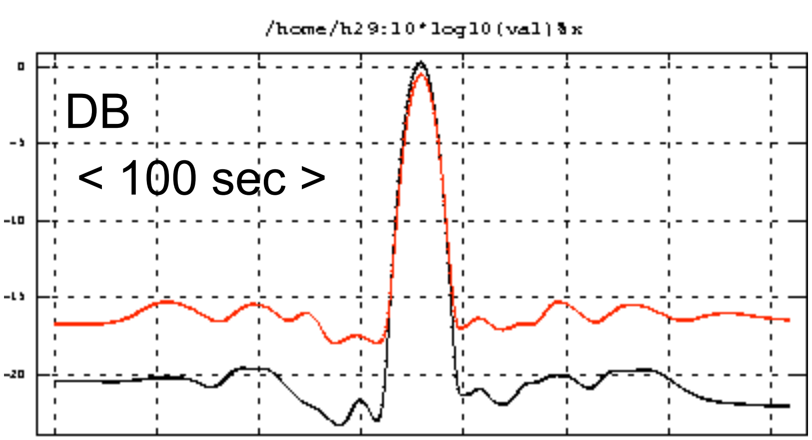
- Curve centers:
Black 1409 MHz
Red 1408 MHz
Blue 1420 MHz
- Curve widths:
Black <29 MHz>
Red <7 MHz>
Blue <4.6 MHz>

-90 ------------------------------> +90



Lobe move with freq for non-zenith source





Angle:
-90 -> +90
1 bin = 0.25 deg